

GAS FOR REMOVING DEPOSIT AND REMOVAL METHOD USING SAME

BACKGROUND OF THE INVENTION

5 The present invention relates to a gas, that is, a cleaning or etching gas, for removing deposits by a gas-solid reaction and a removal method using the gas.

10 In thin-film device production process of semiconductor industry, optical device production process, super steel material production process and the like, various thin films, thick films, powders, whiskers and the like are produced, for example, by chemical vapor deposition, (CVD), physical vapor deposition (PVD), sputtering, and sol-gel process. During the production of these materials, unnecessary deposits in the form of film, whisker or powder are inevitably formed, for example, on a reactor's inner wall and a jig for supporting the object, as well as on the object. This may cause the occurrence of unnecessary particles, making it difficult to produce films, powders, whiskers and the like of good quality. Thus, it becomes necessary to occasionally remove the unnecessary deposits, for example, by cleaning gas. Such a cleaning gas is required, for example, to have (1) a high reaction rate at which the cleaning gas reacts with unnecessary deposits to form volatile compounds, (2) a relative easiness to make the exhaust gas of the cleaning unharmed, and (3) a relative unstableness in the atmosphere to make the impact on the global warming smaller. Conventional examples of the cleaning gas are C_2F_6 , CF_4 , C_4F_8 , NF_3 and ClF_3 . These compounds, however, have the following defects. Firstly, ClF_3 is highly reactive, and thus may do damage to materials conventionally used for the apparatus, when ClF_3 is used at a high temperature or with the assistance of plasma. Secondly, NF_3 is low in reactivity unless the reaction temperature is at least $300^\circ C$, and thus may be impossible to remove unnecessary

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deposits accumulated in the piping of the apparatus and the outside of the plasma region. Furthermore, it is necessary to have a high temperature in order to make the exhaust gas unarmful. Thus, the cost for conducting the cleaning becomes
5 relatively high. Thirdly, each of C_2F_6 , CF_4 and C_4F_8 has the following defects. That is, it may be impossible to remove unnecessary deposits accumulated in the piping of the apparatus and the outside of the plasma region. Furthermore, a fluorocarbon(s) will accumulate by the plasma cleaning. If
10 oxygen is added in order to decrease the amount of the accumulation of the fluorocarbon(s), an oxide(s) will accumulate instead. Since each of C_2F_6 , CF_4 and C_4F_8 is a very stable compound, it is difficult to treat the exhaust gas of the cleaning. In other words, these compounds (gases) will be stably present
15 in the environment, and cause adverse impact against the environment due to their high global warming coefficients or factors. Thus, it is necessary to have a high temperature for the treatment of the exhaust gas. This makes the cost of the treatment relatively high.

20 An etching gas, which is analogous to the above-mentioned cleaning gas, is used for partially removing a thin film material in order to transfer the circuit pattern, for example, of LSI and TFT. Conventional examples of this etching gas are CF_4 , C_2F_6 , CHF_3 , SF_6 , and NF_3 . These gases
25 have a problem of high global warming coefficient. Furthermore, these gases are relatively stable gases. Thus, it is necessary to use a large amount of energy for generating, for example, CF_3 radicals and F radicals, which are useful as etchant. That is, the electric power consumption becomes
30 large. Furthermore, it is relatively difficult to treat the unreacted etching gases, prior to the discharge into the atmosphere. Therefore, there is an urgent demand for an alternative etching gas(es) that can easily be made unarmful

on the global environment and is capable of achieving high precision etching.

SUMMARY OF THE INVENTION

It is therefore an object of the present invention to
5 provide a gas for removing deposits, which gas can easily be made un-
harmful on the global environment after the removal of deposits.

It is a more specific object of the present invention to
provide a cleaning gas for efficiently removing unnecessary
10 deposits accumulated, for example, in an apparatus for producing semiconductor devices, which cleaning gas can easily be made un-
harmful on the global environment after the removal of the deposits.

It is another specific object of the present invention to
15 provide an etching gas for removing, as precisely as originally designed, an unwanted portion of a film deposited on a substrate, for example, for producing thin film devices (e.g., LSI and TFT), which etching gas can easily be made un-
harmful on the global environment after the removal of the unwanted
20 portion.

It is still another object of the present invention to provide a method for removing a deposit by the gas.

According to the present invention, there is provided a gas for removing deposits by a gas-solid reaction. This gas
25 comprises a hypofluorite that is defined as being a compound having at least one OF group in the molecule. We unexpectedly found that various deposits can be removed by the gas and that the gas can easily be made un-
harmful on the global environment after the removal of the deposits. The gas may be
30 a cleaning gas for substantially completely removing the deposits. In other words, this cleaning gas is used for cleaning, for example, the inside of an apparatus for producing semiconductor devices. This cleaning gas comprises 1-100

volume % of the hypofluorite. We unexpectedly found that various unnecessary deposits can efficiently be removed by the cleaning gas. Furthermore, either of plasma-assisted and plasma-less cleanings is made possible by the cleaning gas.

5 Alternatively, the gas according to the present invention may be an etching gas for removing an unwanted portion of a film deposited on a substrate. In other words, the etching gas is used, for example, in pattern transfer operations in the production of semiconductor circuits. We unexpectedly found

10 that the unwanted portion can be removed by the etching gas as precisely as originally designed.

According to the present invention, there is provided a method for removing a deposit by the gas. This method comprises the step (a) bringing the gas into contact with the

15 deposit, thereby to remove the deposit by a gas-solid reaction. The above-mentioned unexpected findings are also obtained by this method.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a sectional view showing a multilayer structure used in the after-mentioned Examples 1-3 and Comparative

20 Example 1, which is prior to an etching of a SiO_2 insulator film with an etching gas; and

Fig. 2 is a view similar to Fig. 1, but showing the multilayer structure after the etching.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

A hypofluorite according to the present invention dissociates more easily than, for example, each of CF_4 , C_2F_6 , C_4F_8 , and NF_3 , and is lower than ClF_3 in reactivity. For example, O-F bond of a hypofluorite, that is, trifluoromethyl-

30 hypofluorite ($\text{CF}_3\text{O-F}$), has a bond dissociation energy of 43.5 kcal/mol. This value is lower than that (61 kcal/mol) of N-F bond of NF_3 and higher than that (37 kcal/mol) of Cl-F of ClF_3 . In other words, $\text{CF}_3\text{O-F}$ releases active fluorine more easily than

NF₃ and is more stable than ClF₃. Although CF₃O-F does not have a high fluorination strength as that of F₂ or ClF₃, it is sufficient to make it possible to conduct a plasma-less cleaning. Furthermore, it is possible to remove deposits (contaminants) accumulated in the outside of the plasma region by using an etching gas comprising a hypofluorite (e.g., CF₃O-F), although it has been impossible by using conventional plasma cleaning gases (e.g., CF₄). It should be noted that the hypofluorite is much smaller than ClF₃ in corrosiveness. That is, the hypofluorite does relatively little damage to general materials used for, for example, an inner wall of the apparatus. The hypofluorite is decomposed in the air, and thus has little to do with the global warming. Furthermore, the cleaning gas or etching gas according to the invention discharged from the apparatus can easily be decomposed by water or an alkali aqueous solution, for example, of alkali scrubber. Thus, the cleaning gas or etching gas itself is not discharged into the environment, nor produces global warming gases (e.g., C₂F₆ and CF₄). Therefore, the cleaning gas or etching gas according to the present invention does not cause substantial environmental problems. The etching gas according to the invention is capable of having a higher etching rate and a higher aspect ratio than those of, for example, CF₄.

In the invention, examples of the deposit, which can be removed by cleaning with the cleaning gas or by etching with the etching gas, are B, P, W, Si, Ti, V, Nb, Ta, Se, Te, Mo, Re, Os, Ru, Ir, Sb, Ge, Au, Ag, As and Cr, and oxides, nitrides, carbides and alloys of these elements. The deposit, which is partially removed by etching with the etching gas, may be formed on a substrate, such as silicon wafer, metal plate, glass plate, single crystal plate, or polycrystalline plate.

In the invention, the hypofluorite optionally has at least one selected from halogen atoms, ether groups, alcohol groups,

carbonyl groups, carboxyl groups, ester groups, amine groups, and amide groups. In general, hypofluorites have very great fluorination strengths. Therefore, it may not be preferable in the invention to use a hypofluorite that has a reducing group or a bond that is unstable in terms of energy level. Preferable examples of the hypofluorite of the invention are CF_3OF , $\text{CF}_2(\text{OF})_2$, $\text{CF}_3\text{CF}_2\text{OF}$, CH_3COOF , $(\text{CF}_3)_3\text{COF}$, $\text{CF}_2\text{HCF}_2\text{OF}$, $(\text{CF}_3\text{CF}_2)(\text{CF}_3)_2\text{COF}$, CH_3OF , CFH_2OF , CF_2HOF , $\text{CF}_3\text{CF}_2\text{CF}_2\text{OF}$, and $(\text{CF}_3)_2\text{CFOF}$. The hypofluorite of the invention may be derived from a halogenated hydrocarbon group, ether, alcohol, carboxylic acid, ester, amine or amide. In the invention, it is optional to use a hypofluorite that has at least two OF groups in the molecule, because this hypofluorite has a reactivity analogous to another hypofluorite having only one OF group in the molecule.

In the invention, it is optional to use a hypofluorite itself as a cleaning gas. That is, this cleaning gas contains 100% of the hypofluorite. This cleaning gas is capable of completely cleaning deposits, which have been deposited on the inside of a chamber and its exhaust pipes. These deposits may be CVD by-products or unnecessary deposits made of materials that are the same as the materials of films formed on, for example, silicon wafer and glass substrates. Furthermore, the cleaning gas of the invention can be used for cleaning a multi-chamber type CVD apparatus, various batch-type CVD apparatuses, a CVD apparatus for epitaxial growth, and the like. The manner of exciting the cleaning gas is not particularly limited. For example, high frequency or microwave may be used for the excitation, depending on the type of the apparatus. It is optional to excite the cleaning gas in the inside of the reaction chamber. Alternatively, it is optional to take a remote plasma method in which the cleaning gas is excited in the outside of the

reaction chamber, and then radical or ion is introduced into the reaction chamber.

In the invention, it is optional to prepare a cleaning gas by mixing a hypofluorite with an inert gas (e.g., He, N₂ and Ar) and/or at least one gas component selected from oxygen and oxygen-containing gases (e.g., CO₂, CO, NO, NO₂, and N₂O). In fact, if deposits containing no oxygen are repeatedly removed, a very small amount of an organic fluoride having a white color accumulates on a low temperature portion of the exhaust pipe(s) of the apparatus. This organic fluoride is assumed to be a polymer made from ions and radicals, such as CF₃O⁺, CF₃⁺ and CF₂⁺, derived from the hypofluorite. We unexpectedly found that the formation of this organic fluoride is prevented by mixing a hypofluorite with the above-mentioned at least one gas component. Although CO₂ and CO of the at least one gas component each contain carbon, which is an element causing the formation of the organic fluoride, these compounds each contain oxygen in the molecules, too. Therefore, it becomes possible to make F-radicals long in lifetime. This may prevent the formation of the polymer. In particular, it is preferable that the at least one gas component is in an amount from 0.4 to 90 volume %, based on the total volume of the at least one gas component and the hypofluorite. If it is less than 0.4 volume %, carbon may remain on the wall of the reactor or the piping after the cleaning. If it is greater than 90 volume %, the oxidation of the surface of the deposit may occur predominantly. This may lower the cleaning rate too much.

In the invention, as mentioned above, the cleaning gas may be a hypofluorite itself or a mixture of a hypofluorite and the at least one gas component selected from oxygen and oxygen-containing gases. Furthermore, the cleaning gas may be diluted with an inert gas (e.g., nitrogen, argon and helium). A suitable cleaning gas is chosen, depending on the type and

thickness of the deposit to be removed, the type of the material of the apparatus, and the like. In case that the cleaning gas is diluted, the hypofluorite concentration of the diluted cleaning gas is preferably at least 1 volume %, more preferably at least 5
5 volume %, still more preferably at least 10 volume %. If it is less than 1 volume %, the reaction rate may become too low.

In the invention, the cleaning conditions are not particularly limited. The temperature of the cleaning is preferably from 10 to 700°C, more preferably from 20 to 600°C.
10 If it is higher than 700°C, the reactor may corrode too much. If it is lower than 10°C, the reaction rate of the cleaning may become too low. The pressure of the cleaning is not particularly limited. In fact, it is preferably from 0.1 to 760 Torr in plasma-less cleaning and preferably from 1 m Torr to 10
15 Torr in plasma-assisted cleaning

In the invention, the etching manner and the reaction conditions of the etching, in which the etching gas of the invention is used, are not particularly limited. For example, the etching may be reactive ion etching (RIE) or electron
20 cyclotron resonance (ECR) plasma-assisted etching. Due to the use of a hypofluorite for the etching gas, fluorine radicals reach the surface of a SiO₂ insulator film 2 that is to be partially removed by the etching gas (see Fig. 1). Furthermore, CF_n ions impinge on the surface of the film 2. With this, the film 2
25 is etched away in a vertical direction, thereby to form, for example, a contact hole in the film 2, as shown in Fig. 2. The side walls of the contact hole are protected by the accumulation of a fluorocarbon polymer, thereby to achieve an anisotropic etching. In particular, a large amount of CF₃⁺ ions are
30 produced, as well as fluorine radicals, in plasma by the hypofluorite. Therefore, the etching gas of the invention is superior in etching efficiency. Furthermore, the etching gas of the invention contains oxygen of the hypofluorite. With this, a

fluorocarbon film accumulated on the side walls of the contact hole can efficiently be removed, thereby to conduct an anisotropic etching.

In the invention, the etching can be conducted under various dry etching conditions, for example, of plasma etching, reactive plasma etching, and microwave etching. The etching gas of the invention may be prepared by mixing a hypofluorite with an inert gas (e.g., He, N₂ and Ar) and/or at least one other gas selected from, for example, HI, HBr, HCl, CO, NO, O₂, CH₄, NH₃, H₂, C₂H₂, and C₂H₆. In fact, it is preferable to add, to the hypofluorite, at least one first gas component selected from hydrogen and hydrogen-containing gases (e.g., CH₄, NH₃, HI, HBr, C₂H₂, and HCl), in the preparation of the etching gas, for the purposes of (1) reducing the amount of fluorine radicals, which accelerate isotropic etching, and (2) increasing the reaction selectivity toward SiO₂ over Si. Furthermore, the flow rate ratio of the at least one first gas component to the hypofluorite is preferably not greater than 10:1. If this ratio is greater than 10:1, the amount of fluorine radicals, which are useful for the etching, may become too low. It is preferable to add, to the hypofluorite, at least one second gas component selected from oxygen and oxygen-containing gases (e.g., CO, NO, N₂O, and NO₂), in the preparation of the etching gas, for the purpose of increasing the etching rate of metals over oxides and nitrides. It is particularly preferable that the flow rate ratio of the at least one second gas component to the hypofluorite is not greater than 4:1. If this ratio is greater than 4:1, the amount of fluorine radicals, which are useful for the etching, may become too low.

In the invention, the gas pressure of the etching is preferably not higher than 5 Torr, in order to conduct anisotropic etching. If the gas pressure is lower than 0.001 Torr, the etching rate may become too slow. The flow rate of

Table 1

	Etching Gas	Etching Rate (Å/min)
Example 1	CF ₃ OF	8,105
Example 2	CF ₃ CF ₂ OF	7,769
Example 3	(CF ₃) ₃ COF	9,606
Example 4	CF ₂ (OF) ₂	20,832

EXAMPLES 5-44 & COMPARATIVE EXAMPLE 1

In these examples and comparative example, Examples 1-4 were repeated except in that the etching gas types were changed as shown in Table 2, that the etching gas pressure was 10 Torr in place of 0.5 Torr, that the gas temperature was changed as shown in Table 2, and that the application of a high frequency power was omitted. The results (etching rates) are shown in Table 2.

Table 2

	Temp. (°C)	Etching Gas	Etching Rate (Å/min)
Example 5	20	CF ₃ OF	1,040
Example 6		CF ₂ (OF) ₂	1,953
Example 7		CF ₃ CF ₂ OF	990
Example 8		(CF ₃) ₃ COF	960
Example 9		CF ₂ HCF ₂ OF	780
Example 10		(CF ₃ CF ₂)(CF ₃) ₂ COF	970
Example 11		CF ₃ OF	480
Example 12		CFH ₂ OF	660
Example 13		CF ₂ HOF	770
Example 14		CF ₃ CF ₂ CF ₂ OF	910
Example 15		(CF ₃) ₂ CFOF	930
Example 16	100	CF ₃ OF	3,230
Example 17		CF ₂ (OF) ₂	4,385
Example 18		CF ₃ CF ₂ OF	2,780
Example 19	200	CF ₃ OF	9,810
Example 20		CF ₂ (OF) ₂	10,259
Example 21		CF ₃ CF ₂ OF	6,620
Example 22	300	CF ₃ OF	20,500
Example 23		CF ₂ (OF) ₂	49,853
Example 24		CF ₃ CF ₂ OF	9,880

Table 2-continued

Example 25	400	CF ₃ OF	32,900
Example 26		CF ₂ (OF) ₂	59,560
Example 27		CF ₃ CF ₂ OF	14,700
Com. Ex. 1		CF ₄	0
Example 28	500	CF ₃ OF	53,600
Example 29		CF ₂ (OF) ₂	71,265
Example 30		CF ₃ CF ₂ OF	23,000
Example 31	600	CF ₃ OF	78,800
Example 32		CF ₂ (OF) ₂	98,654
Example 33		CF ₃ CF ₂ OF	37,100
Example 34	700	CF ₃ OF	99,600
Example 35		CF ₂ (OF) ₂	115,893
Example 36		CF ₃ CF ₂ OF	45,200
Example 37		(CF ₃) ₃ COF	37,000
Example 38		CF ₂ HCF ₂ OF	31,000
Example 39		(CF ₃ CF ₂)(CF ₃) ₂ COF	34,500
Example 40		CF ₃ OF	25,000
Example 41		CFH ₂ OF	31,500
Example 42		CF ₂ HOF	33,000
Example 43		CF ₃ CF ₂ CF ₂ OF	36,000
Example 44		(CF ₃) ₂ CFOF	35,200

EXAMPLE 45

In this example, a plasma CVD was conducted by using tetraethylsilicate (TEOS) and oxygen as raw materials, in an apparatus for conducting the plasma CVD. With this, SiO₂ having a thickness of about 0.05 to about 20 μm deposited on the wall of the apparatus. The inside of the apparatus was cleaned at 20°C for 20 min by feeding cleaning gases of CF₃OF, CF₂(OF)₂ and CF₃CF₂OF by turns and by applying a high frequency power to the lower electrode of the apparatus. Each cleaning gas had a pressure of 1 Torr and a flow rate of 100 SCCM. In this etching, the frequency of the high frequency power source was 13.56 MHz, the power applied to the lower electrode was 0.2 W/cm², and the distance between the lower and upper electrodes was 50mm. It was found by an

observation of the inside of the apparatus that the SiO_2 was completely removed by the cleaning with each cleaning gas.

EXAMPLE 46

A tungsten film was formed by a thermal CVD in a cold wall type apparatus for conducting the CVD. Then, it was found that the temperature in the vicinity of a heater disposed in the reactor was 500°C , that the temperature of a gas diffusion plate was 40°C , and that the temperature of the reactor wall was from 20 to 300°C . Furthermore, it was found that unnecessary tungsten films deposited in many positions in the apparatus. The thickest tungsten film deposited therein had a thickness of about $120\ \mu\text{m}$. It was further found that a tungsten oxide powder deposited in the piping of the apparatus. After the formation of the tungsten film, a first cleaning was conducted by allowing a cleaning gas of CF_3OF to flow through the apparatus at a flow rate of 1 standard liter per minute (SLM) for 30 minutes. Then, it was found by an observation of the inside of the apparatus that the tungsten film of the inside of the reactor and the tungsten oxide powder of the piping were completely removed by the first cleaning. Then, a tungsten film was formed again in the same manner as above in the apparatus. After that, a second cleaning was conducted in the same manner as that of the first cleaning except in that CF_3OF was replaced with $\text{CF}_3\text{CF}_2\text{OF}$. Then, a tungsten film was formed again in the same manner as above in the apparatus. After that, a third cleaning was conducted in the same manner as that of the first cleaning except in that CF_3OF was replaced with $(\text{CF}_3)_3\text{COF}$. Similar to the above, it was found by an observation of the inside of the apparatus that the tungsten film of the inside of the reactor and the tungsten oxide powder of the piping were completely removed by the second and third cleanings.

EXAMPLE 47

At first, four test pieces were prepared by a thermal CVD by respectively forming a tungsten (W) film, a WSi film, a TiC film and a Ta₂O₅ film on four nickel substrates each having a length of 10 mm and a width of 20 mm and a thickness of 2 mm. Each film had a thickness of 50 μ m. Then, these four test pieces were put on the lower electrode of a plasma CVD apparatus. Then, an etching was conducted for 10 min at 20°C by allowing an etching gas of CF₃OF to flow through the apparatus and by applying a high frequency power to the lower electrode. This etching gas had a pressure of 0.5 Torr and a flow rate of 100 SCCM. In this etching, the frequency of the high frequency power source was 13.56 MHz, the power applied to the lower electrode was 0.2 W/cm², and the distance between the lower and upper electrodes was 50mm. After the etching, the test pieces were taken out of the CVD apparatus and then analyzed with an X-ray microanalyzer. With this, the peaks of W, Si, Ti and Ta were not found.

EXAMPLE 48

In this example, Example 47 was repeated except in that a Mo film, a Re film and an Nb film, each having a thickness of 50 μ m, were respectively formed on three nickel substrates each having the same dimensions as those of Example 47 and that the etching was conducted for 3 min. The peaks of Mo, Re and Nb were not found by an analysis with X-ray microanalyzer.

EXAMPLE 49

In this example, Example 47 was repeated except in that a TiN film and a Ti film, each having a thickness of 5 μ m, were respectively formed by sputtering on two nickel substrates each having the same dimensions as those of Example 47. The peak of Ti was not found by an analysis with X-ray microanalyzer.

EXAMPLE 50

In this example, Example 47 was repeated except in that an Au film, an Ag film and a Cr film, each having a thickness of $2\mu\text{m}$, were respectively formed by vacuum deposition on three nickel substrates each having the same dimensions as those of Example 47, that the etching gas flow rate was 10 SCCM, and that the power applied to the lower electrode was 0.315 W/cm^2 . The peaks of Au, Ag and Cr were not found by an analysis with X-ray microanalyzer.

EXAMPLE 51

At first, a nickel vessel was charged with commercial phosphorus (white phosphorus), Ta, As, Ge, Se and B powders, each being in an amount of 5 mg. Then, the nickel vessel was put on the lower electrode of a plasma CVD apparatus. Then, an etching was conducted for 10 min at 20°C by allowing an etching gas of CF_3OF to flow through the apparatus and by applying a high frequency power to the lower electrode. This etching gas had a pressure of 1 Torr and a flow rate of 10 SCCM. In this etching, the frequency of the high frequency power source was 13.56 MHz, the power applied to the lower electrode was 0.315 W/cm^2 , and the distance between the lower and upper electrodes was 50mm. After the etching, it was found by an observation of the vessel and the inside of the apparatus that all the powders were completely removed.

EXAMPLES 52-64

In each of these examples, a silicon film was formed by using SiH_4 as a raw material in an apparatus. After that, there were found in the apparatus silicon and polysilane powders, which were deposited in a reactor of the apparatus, and a polysilane powder, which was deposited in the piping of the apparatus. This piping is outside of the plasma region. Then, a plasma-assisted cleaning was conducted a certain times as shown in Table 3 for 30 min per one time of the cleaning for

the purpose of removing these powders of the apparatus. In this cleaning, a cleaning gas of CF_3OF was allowed to flow through the apparatus at a flow rate of 1 SLM under a pressure of 1 Torr. Furthermore, oxygen and nitrogen were selectively
 5 allowed to flow therethrough, as shown in Table 3. During the cleaning, the temperature of the inside of the piping was 20°C , and that of the inside of the reactor was from 40 to 400°C .

After the cleaning, the inside of the apparatus was observed, and the result of this observation is shown in Table 3. In Table
 10 3, \bigcirc means that the powders were completely removed from the inside of the reactor and the piping, and the deposition of an organic fluoride did not occur; \triangle means that the powders were completely removed from the inside of the reactor and the piping, but the deposition of an organic fluoride in the form of
 15 powder or film was found at an end portion (particularly a low temperature portion) of the piping; and \square means that a silicon oxide formed by oxidation of the polysilane powder deposited. In each of Examples 52-64, at least the inside of the reactor was cleaned.

Table 3

	O_2 Flow Rate (SCCM)	N_2 Flow Rate (SCCM)	The Number of Cleanings (time(s))	Observation Result after Cleaning
Example 52	0	0	1	\bigcirc
Example 53	0	0	2	\bigcirc
Example 54	0	0	3	\triangle
Example 55	1	0	3	\triangle
Example 56	3	0	3	\triangle
Example 57	4	0	3	\bigcirc
Example 58	4	0	10	\triangle
Example 59	100	0	10	\bigcirc
Example 60	500	0	10	\bigcirc
Example 61	50	50	10	\bigcirc
Example 62	5,000	0	10	\bigcirc
Example 63	8,000	0	10	\bigcirc
Example 64	9,000	0	10	\square

EXAMPLES 65-70

In each of these examples, a silicon film was formed in an apparatus by using SiH_4 as a raw material. After that, there were found in the apparatus silicon and polysilane powders, which were deposited in a reactor of the apparatus, and a polysilane powder, which was deposited in a piping of the apparatus. This piping was outside of the plasma region. Then, a plasma-assisted cleaning was repeatedly conducted for 30 min per one time of the cleaning for the purpose of removing these powders of the apparatus. In this cleaning, a cleaning gas of CF_3OF was allowed to flow through the apparatus at a flow rate of 1 SLM under a pressure of 1 Torr. Furthermore, an oxygen-containing gas shown in Table 4 was allowed to flow therethrough, together with CF_3OF . During the cleaning, the temperature of the inside of the piping was 20°C , and that of the inside of the reactor was from 40 to 400°C . After the cleaning, the inside of the apparatus was observed, and the result of this observation is shown in Table 4. In Table 4, \bigcirc means the same as that of Table 3 of Examples 52-64.

Table 4

	Oxygen-containing Compound	Flow Rate of Oxygen-containing Compound (SCCM)	Observation Result after Cleaning
Example 65	CO_2	20	\bigcirc
Example 66	CO	50	\bigcirc
Example 67	NO	20	\bigcirc
Example 68	NO	100	\bigcirc
Example 69	NO_2	5	\bigcirc
Example 70	N_2O	10	\bigcirc

EXAMPLE 71

A thermal CVD was conducted in an apparatus such that a tungsten film having a thickness from 10 to $20\ \mu\text{m}$ was deposited on the wall of a reactor of this apparatus. Separately, a mechanism for exciting a gas with microwave was attached with the reactor via a piping. Then, a remote plasma-assisted cleaning of the apparatus was conducted for 10 min using

microwave plasma. In this cleaning, a cleaning gas of CF_3OF was allowed to flow at a flow rate of 1,000 SCCM under a pressure of 0.1 Torr. The microwave output was 50W (13.56 MHz), and the substrate temperature was 18°C . After the
5 cleaning, it was found that the inside of the reactor was completely cleaned and that a powder (i.e., a mixture of tungsten and tungsten oxide) deposited in the piping was completely removed.

EXAMPLE 72

10 In this example, Example 71 was repeated except in that $\text{CF}_2(\text{OF})_2$ was used as the cleaning gas. After the cleaning, it was found that the inside of the reactor was completely cleaned and that a powder (i.e., a mixture of tungsten and tungsten oxide) deposited in the piping was completely removed.

15 EXAMPLES 73-75 & COMPARATIVE EXAMPLE 2

In each of these examples and comparative example, as shown in Fig. 1, a multilayer structure was prepared by forming a SiO_2 insulator film 2 and a resist mask 3 on a single crystal silicon wafer 1. Then, an opening was formed in the resist
20 mask, as illustrated in Fig. 1. After that, the multilayer structure shown in Fig. 1 was put into an etching apparatus equipped with a power source for supplying a high frequency power of 13.56 MHz. Then, an etching of an exposed portion of the insulator film 2 was conducted for the purpose of making a
25 contact hole in the insulator film 2, as shown in Fig. 2. In the etching, an etching gas shown in Table 5 was allowed to flow through the apparatus at a flow rate of 50 SCCM under a pressure of 0.02 Torr with a RF (radio frequency) power density of 2.2 W/cm^2 . After the etching, the etching rate of this etching,
30 the selectivity of the etching toward the insulator film 2 over the resist 3, and the aspect ratio were determined, and their results are shown in Table 5. Furthermore, the loss of shoulder

portions 4 of the resist 3 (see Fig. 2) was checked, and its result is also shown in Table 5.

Table 5

	Etching Gas	Etching Rate (Å/min)	Selectivity	Aspect Ratio	Loss of Shoulder Portions
Example 73	CF ₃ OF	5,453	6	At least 7	No
Example 74	C ₂ F ₅ OF	4,026	7	At least 7	No
Example 75	CF ₂ (OF) ₂	7,563	6	At least 6	No
Com. Ex. 2	CF ₄	608	4	5	Yes

EXAMPLE 76

5 In this example, Example 73 was repeated except in that an argon gas with a flow rate of 200 SCCM was added to the etching gas (CF₃OF) of Example 73 and that the flow rate of CF₃OF was 10 SCCM.

EXAMPLES 77-84

10 In each of these examples, Example 73 was repeated except in that a hydrogen-containing gas with a flow rate shown in Table 6 was added to the etching gas (CF₃OF) of Example 73 and the flow rate of CF₃OF was changed as shown in Table 6. In fact, the total flow rate of CF₃OF and the hydrogen-
15 containing gas was adjusted to 100 SCCM in Examples 77-84, as shown in Table 6. The results of the etching rates of the insulator film 2, which is made of SiO₂, and the silicon wafer 1, which is made of Si, are shown in Table 6. It is understood from Table 6 that the etching rate of the silicon wafer 1 has
20 decreased drastically with the increase of the flow rate of the hydrogen-containing gas, and in contrast the etching rate of the SiO₂ insulator film was relatively stable even with the increase of the flow rate of the hydrogen-containing gas. In other words, it is understood that the SiO₂ insulator film can selectively be
25 etched away by adding a hydrogen-containing gas into the etching gas (i.e., hypofluorite), over the silicon wafer. Furthermore, similar results of the etching rates were also

obtained by respectively using CH_4 , HI , HCl and HBr as hydrogen-containing gases.

Table 6

	Flow Rate of CF_3OF (SCCM)	Hydrogen-containing Gas	Flow Rate of Hydrogen-containing Gas (SCCM)	Etching Rate ($\text{\AA}/\text{min}$)	
				Insulator Film	Silicon Wafer
Example 77	100	H_2	0	5,560	40,856
Example 78	99.9	H_2	0.1	5,560	38,856
Example 79	99	H_2	1	5,560	18,856
Example 80	90	H_2	10	5,260	5,189
Example 81	70	H_2	30	5,240	889
Example 82	60	H_2	40	5,060	11
Example 83	10	H_2	90	3,596	0.5
Example 84	60	C_2H_2	40	5,010	9

EXAMPLE 85

5 In this example, a first etching was conducted by etching a tungsten film in the same way as that of Example 73. The etching rate of the first etching was $39,554 \text{\AA}/\text{min}$. A second etching was conducted in the same way as that of the first etching except in that oxygen with a flow rate of 10 SCCM was

10 added to the etching gas (CF_3OF). The etching rate of the second etching was $400,259 \text{\AA}/\text{min}$. A third etching was conducted in the same way as that of the first etching except in that the tungsten film was replaced with a SiO_2 film. The etching rate of the third etching was $5,453 \text{\AA}/\text{min}$. A fourth

15 etching was conducted in the same way as that of the third etching except in that oxygen with a flow rate of 10 SCCM was added to the etching gas (CF_3OF). The etching rate of the fourth etching was $9,865 \text{\AA}/\text{min}$. It is understood from the etching rates of the first to fourth etchings that the etching rate

20 of a metal film (tungsten film) increases more greatly by adding oxygen to an etching gas, than that of an oxide film (SiO_2) does.

The entire disclosure of each of Japanese Patent
Application Nos. 9-349536 filed on December 18, 1997, 10-
239338 filed on August 26, 1998, and 10-239339 filed on August
26, 1998, including specification, claims, drawings and
5 summary, is incorporated herein by reference in its entirety.